Module Surveys for Supermodule 1

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Introduction

As each plane of the MINOS far detector is erected, the scintillator module positions are surveyed using the Vulcan Spatial Measurement System, which is described elsewhere.[1] The Vulcan is used to measure the coordinates of two alignment holes on each module. These are the two holes closest to the center of the plane and are, in most cases, the reference points for strip alignment when the modules are mapped with a radioactive source. The exceptions are the bypass modules, which will receive additional discussion in a later section. Although the Vulcan collects data in the x, y, and z coordinates, only the x and y data are considered in this note.

Module Arrangement

Each plane comprises 8 scintillator modules in the pattern A, B, C/E, D/F, D/F, C/E, B, A. U planes are those measuring the U coordinate (modules perpendicular to U); V planes measure the V coordinate (modules perpendicular to V). The U planes are built using the E and F modules in the center; the V planes are built with the C and D modules. The alignment holes are accessed from the north side (steel side) of the plane. Each module has three alignment holes on each side. The alignment holes nearest the clear fiber connector, referred to here as the primary alignment holes, are used as the reference points in mapping the module. Once the plane is erected, all of the primary alignment holes can be reached with the Vulcan tooling ball probe except those for the B modules. On these modules, the steel covers the primary alignment holes and their position is estimated by measuring the #2 and #3 alignment holes and projecting to the #1 position. This introduces an additional uncertainty in the measurement, but overall the results are quite good. The spreadsheet that performs this calculation also makes a quality control check by comparing the calculated distances from the #1 top - #3 bottom holes and #3 top - #1 bottom holes with the known average distance as measured in the factory.

Module Alignment

The following plots show how the modules are aligned in Supermodule 1. The "Angular Distribution" plots show the distribution of angles between the x axis and a line connecting the upper and lower primary alignment holes on a module. Each plot corresponds to a single module position for either U planes or V planes. There is an entry for each module that was successfully measured with the Vulcan. Note that $\pi/4 = 0.7854$, so the mean of any given distribution is well-aligned with the U or V axis. The "Deviation" plots show the difference between the measured position of the alignment holes and the position expected if the angle were exactly $\pi/4$ radians. The plots show that these deviations are less than the resolution of the Vulcan system, which has been measured to be about 3.7 mm.[2] Hence, the modules in any given position are aligned with each other to within the sensitivity of the Vulcan. Any general misalignment of the modules is too small to detect with our survey methods.

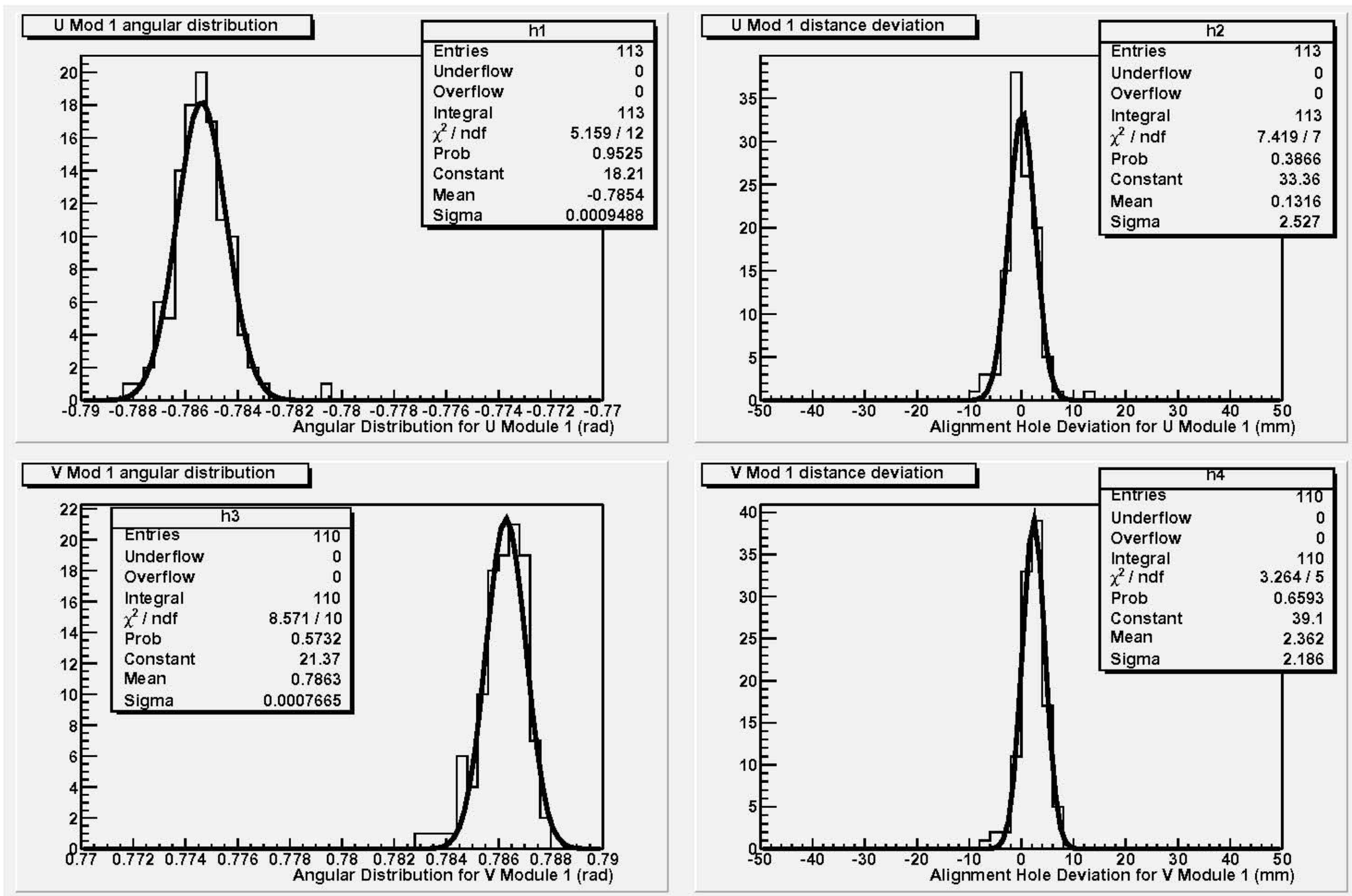

Figure 1 Angular and corresponding distance deviations for module 1 (lower A module) for both U and V planes.

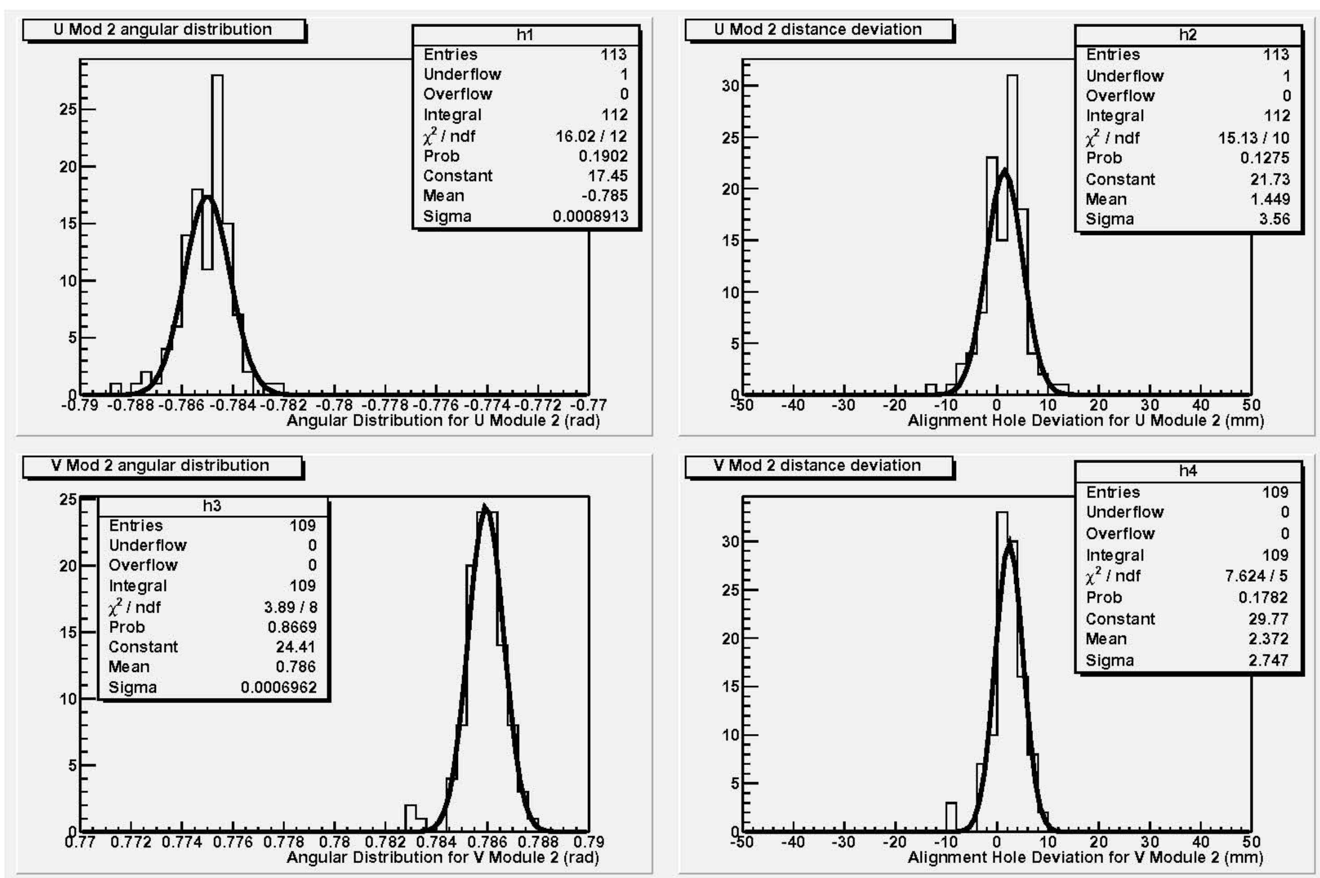

Figure 2 Angular and corresponding distance deviations for module 2 (lower B module). For these modules, the primary alignment hole location cannot be measured directly, but is inferred from measurements of the #2 and #3 alignment hole positions.

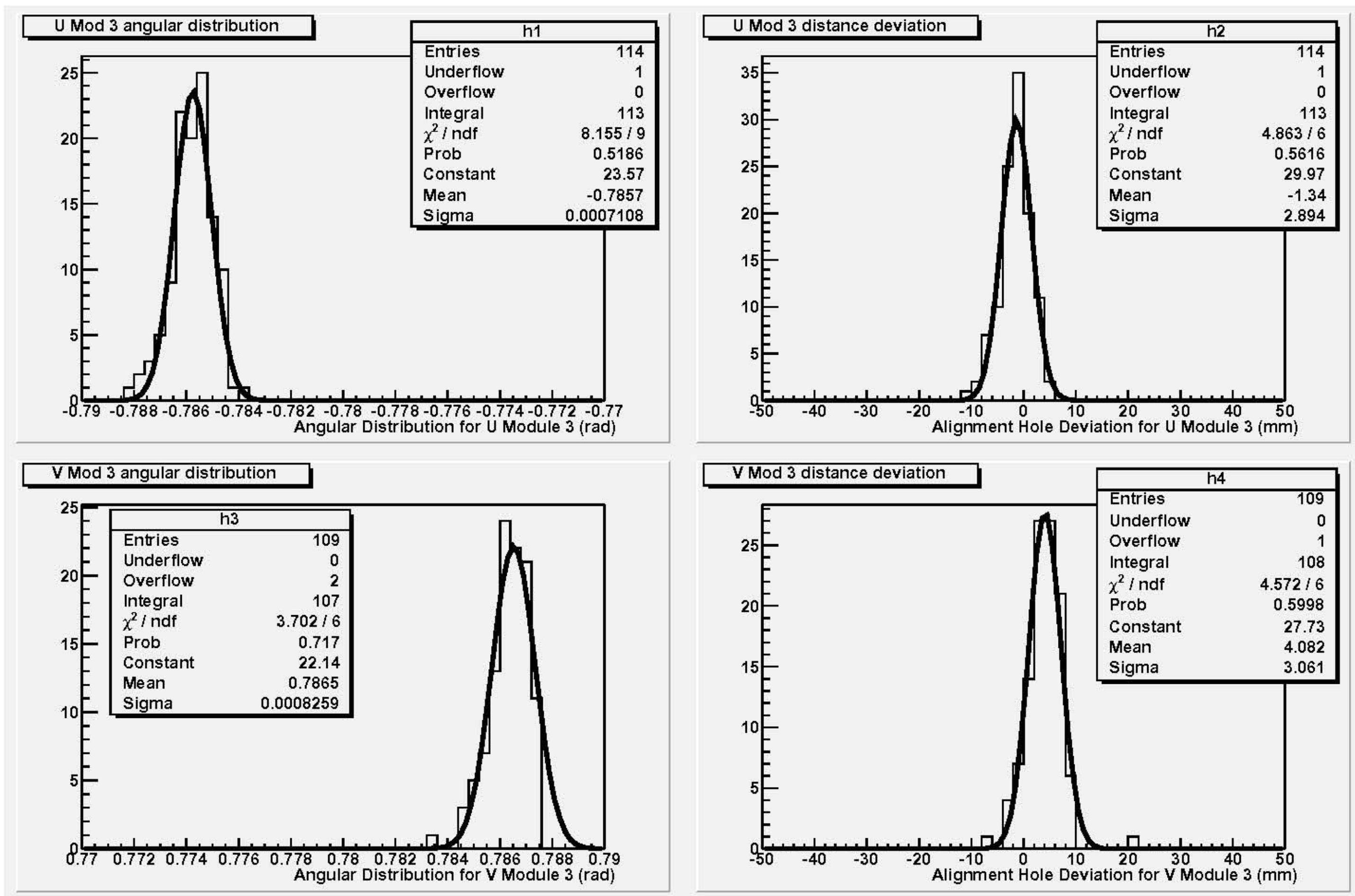

Figure 3 Angular and corresponding distance deviations for module 3 (lower E module for U planes; lower C module for V planes).

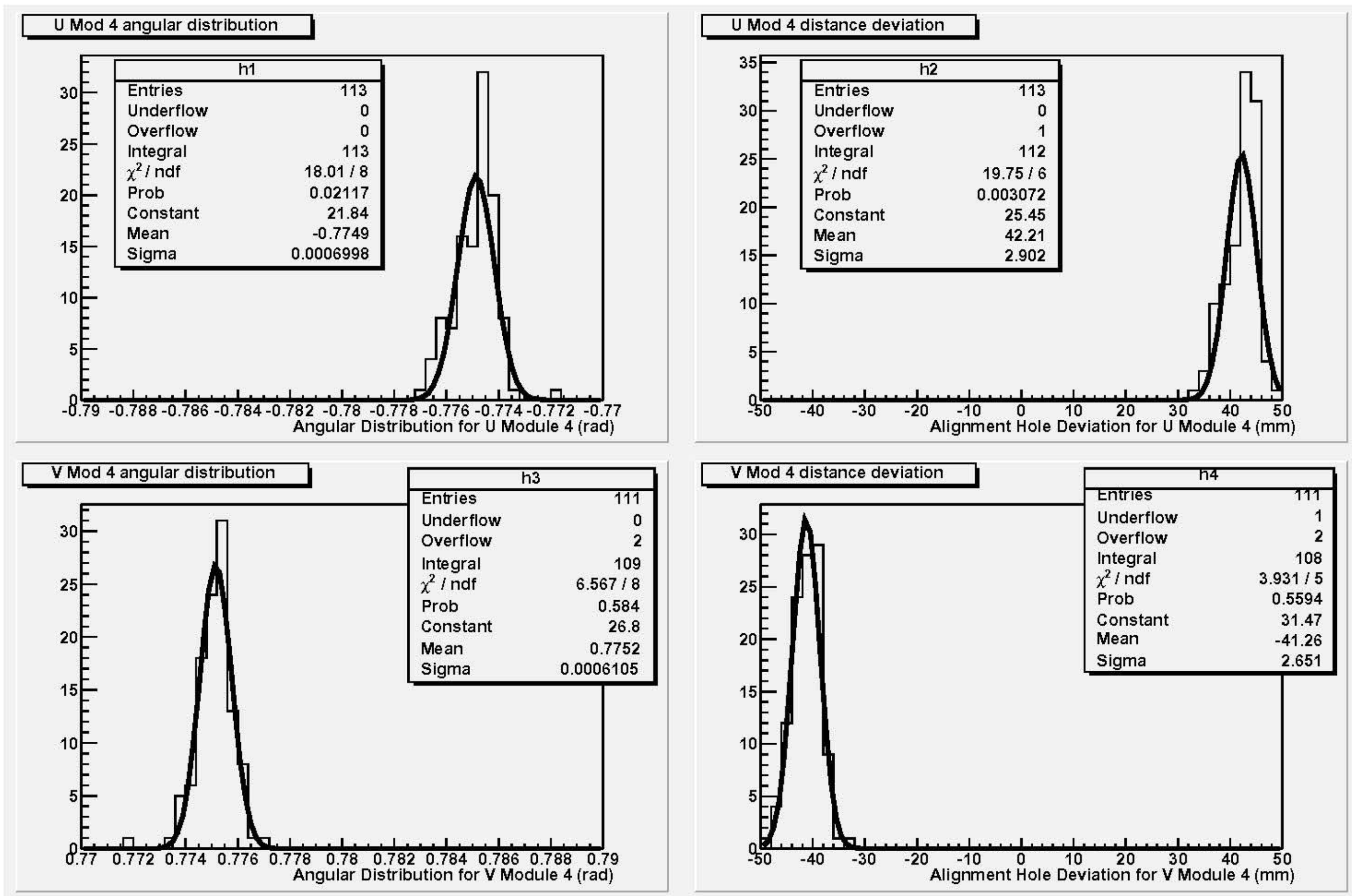

Figure 4 Angular and corresponding distance deviations for module 4 (lower bypass module; F for U planes; D for V planes).

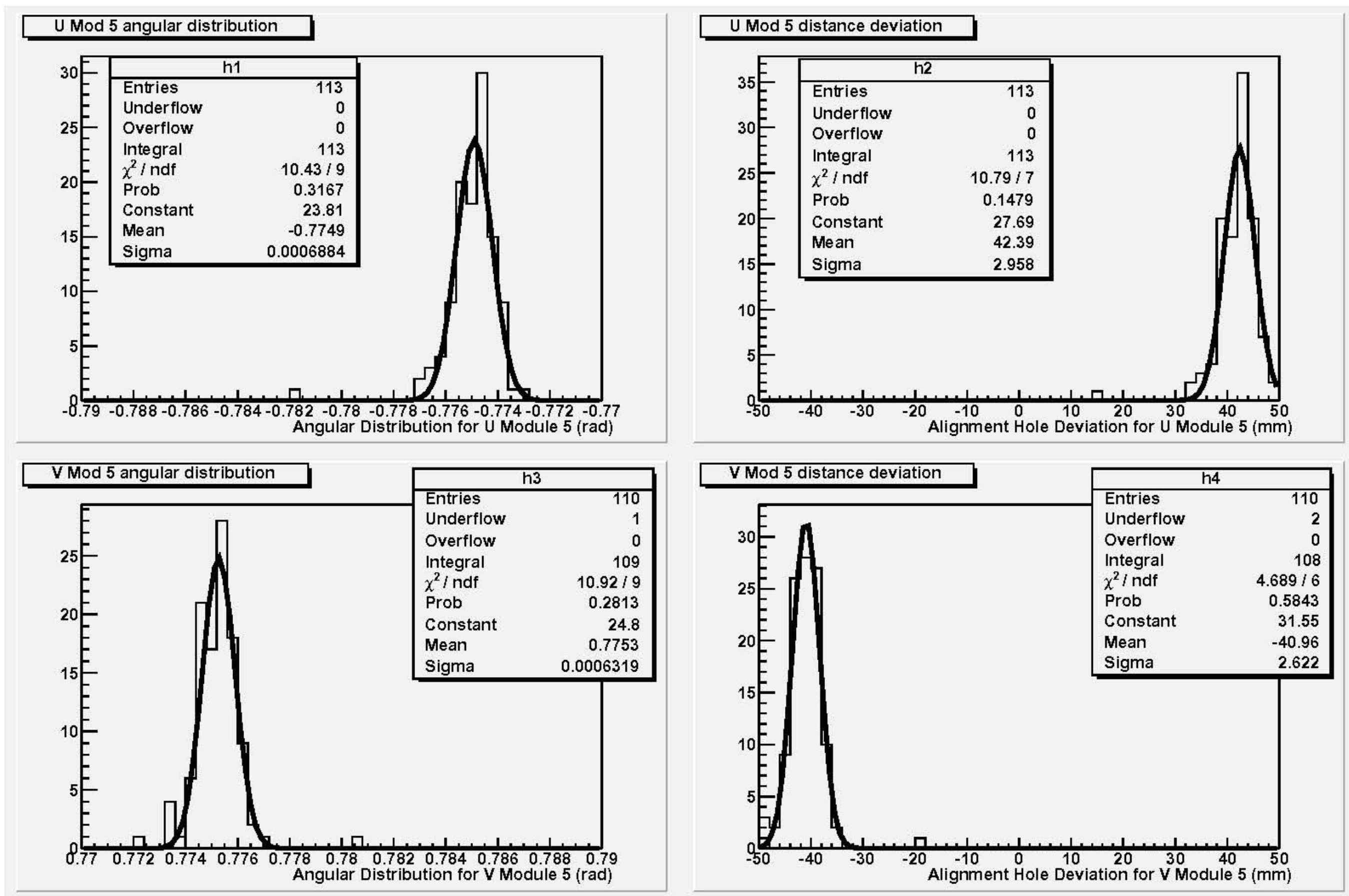

Figure 5 Angular and corresponding distance deviations for module 5 (upper bypass module; F for U planes; D for V planes).

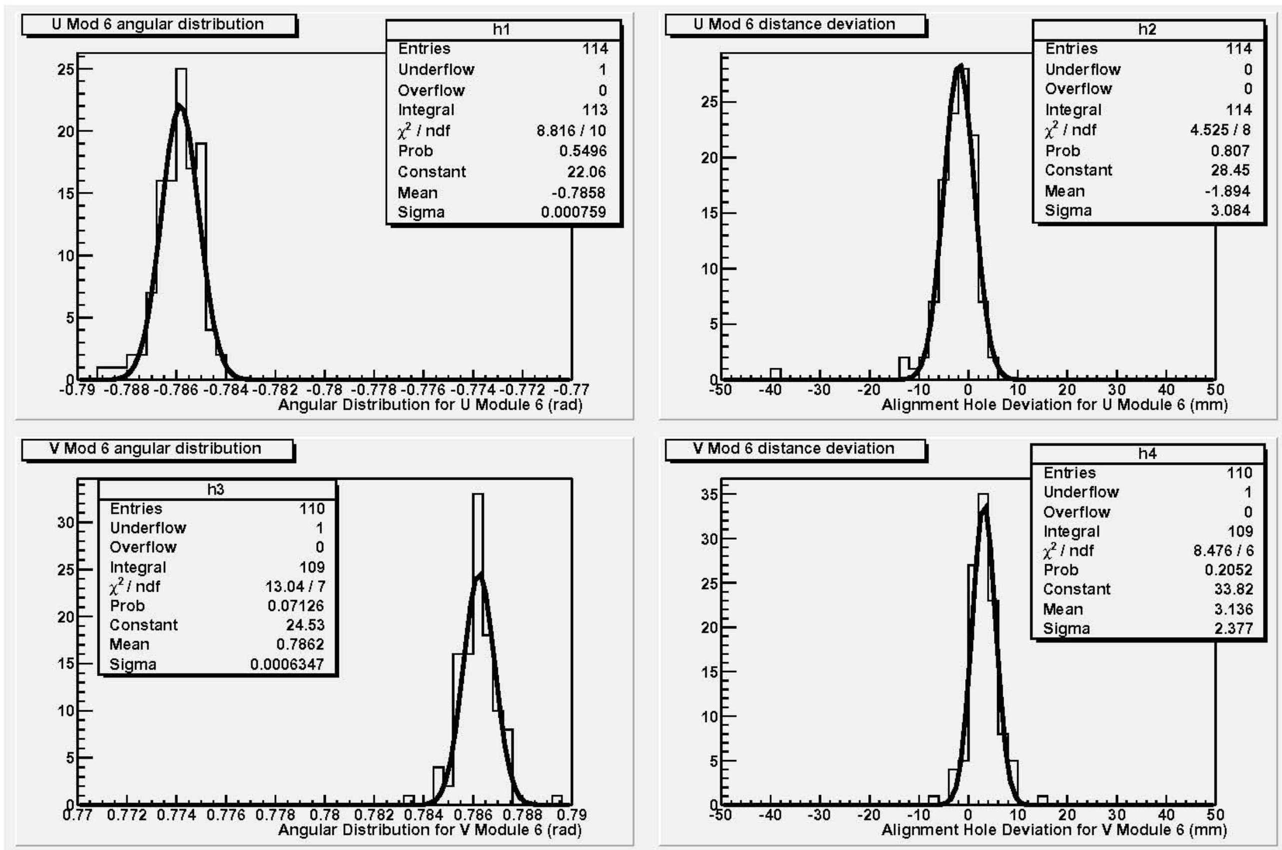

Figure 6 Angular and corresponding distance deviations for module 6 (upper E module for U planes; upper C module for V planes).

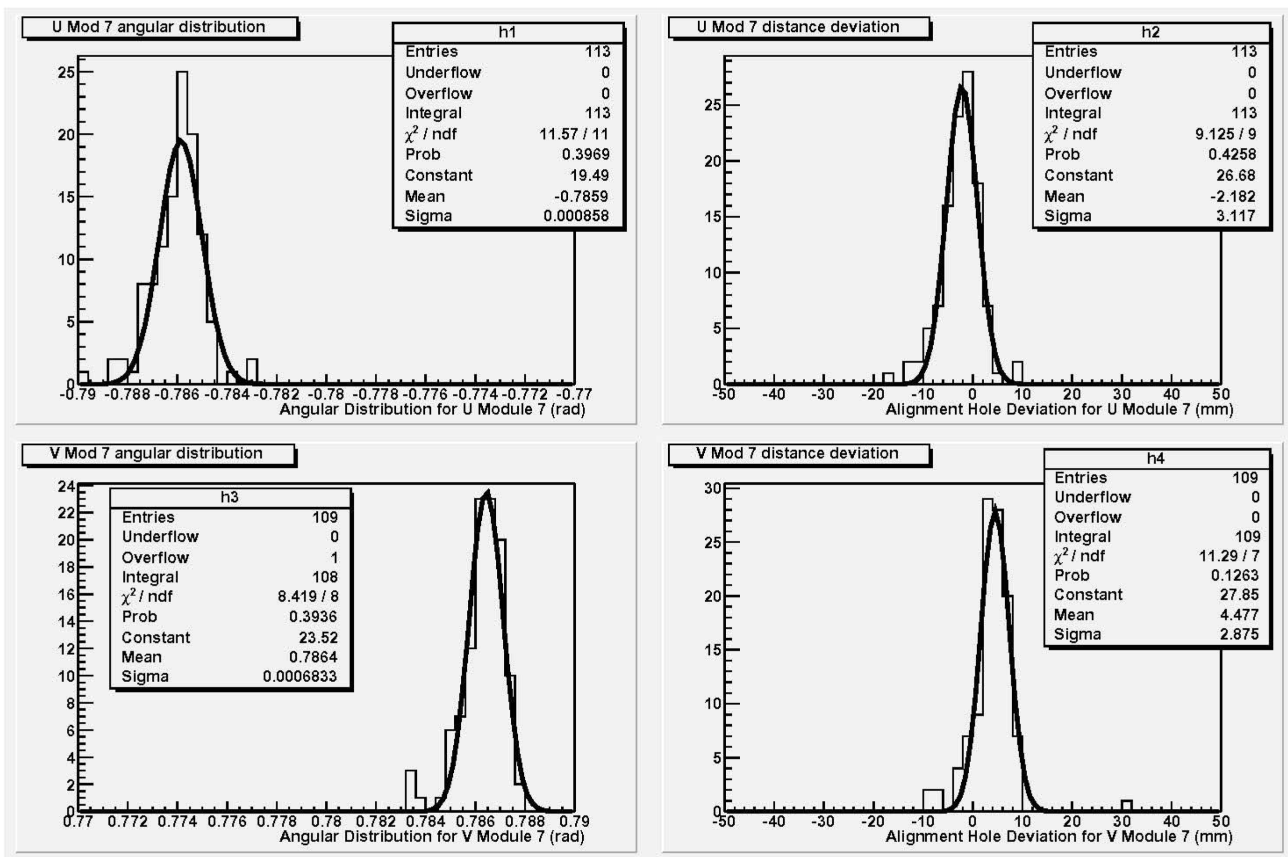

Figure 7 Angular and corresponding distance deviations for module 7 (upper B module). For these modules, the primary alignment hole location cannot be measured directly, but is inferred from measurements of the #2 and #3 alignment hole positions.

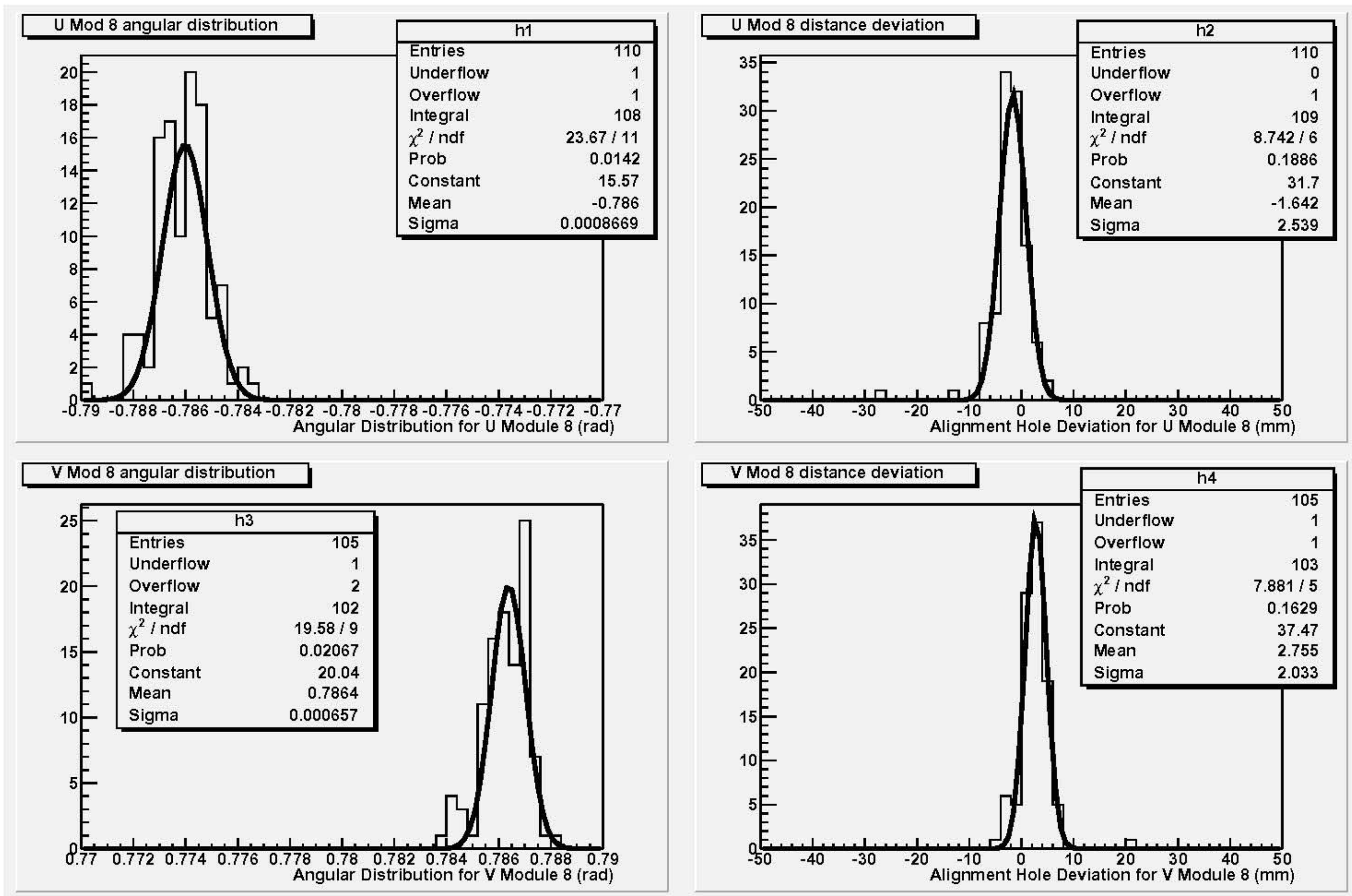

Figure 8 Angular and corresponding distance deviations for module 8 (upper A module).

<u>Bypass Modules</u>
Figure 4 and Figure 5 show the deviations of the bypass modules. These are seen to be much greater than those of the other modules because of the way these modules are constructed. The primary alignment holes, as defined here, are always those nearest to the center of the module and, in most cases are also those nearest to the clear fiber connectors. However, because the upper and lower connectors of the bypass modules are on opposite sides, the primary alignment holes are skewed relative to the strips, which are actually parallel to the module casing. The figures indicate a difference of about 10 milliradians between the strip alignment and a line connecting the primary alignment holes. The distance deviation plots show clearly that the angular deviation of the module cannot be real, since a deviation on the order of 40 mm would be visually obvious and would not allow the bypass modules to fit between modules 3 and 6. If we set the average angle of modules 3 and 6 to be the average angle of the bypass modules, this is equivalent to rotating the bypass alignment holes to a new "virtual" position. From Figure 3 and Figure 6, the average angle is approximately 0.786 rad. Corrections are applied according to the following table.

Module Type	Top Alignment Hole	Bottom Alignment Hole
U	$x \rightarrow x + \delta x$	$x \rightarrow x - \delta x$
U	$y \rightarrow y + \delta y$	$y \rightarrow y - \delta y$
V	$x \rightarrow x - \delta x$	$x \rightarrow x + \delta x$
V	$y \rightarrow y + \delta y$	$y \rightarrow y - \delta y$

Table 1 Corrections to bypass module survey data. Applying these lines up the strips on the plane rather than the alignment holes, which are skewed.

For SM1,

$$\begin{aligned}\delta x &= 4025.0\,\mathrm{mm} \times \left[\cos(.775) - \cos(.786)\right] \\ &= 31.2\,\mathrm{mm}\end{aligned} \qquad (1a),$$

$$\begin{aligned}\delta y &= 4025.0\,\mathrm{mm} \times \left[\sin(.786) - \sin(.775)\right] \\ &= 31.5\,\mathrm{mm}\end{aligned} \qquad (1b).$$

The factor of 4025.0 mm is half the average length of the modules as measured at the factory.

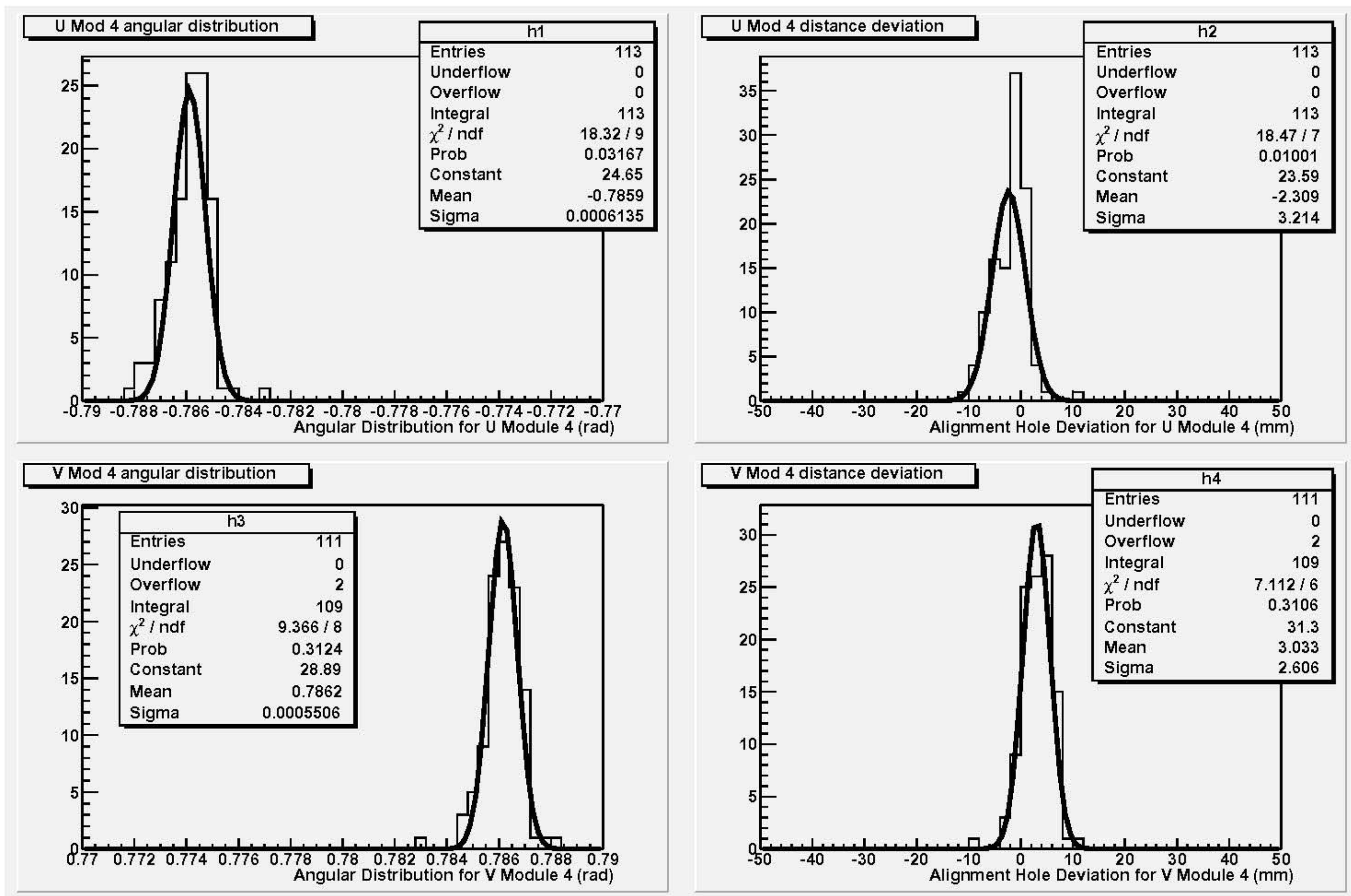

Figure 9 Module 4 alignments using virtual alignment hole correction.

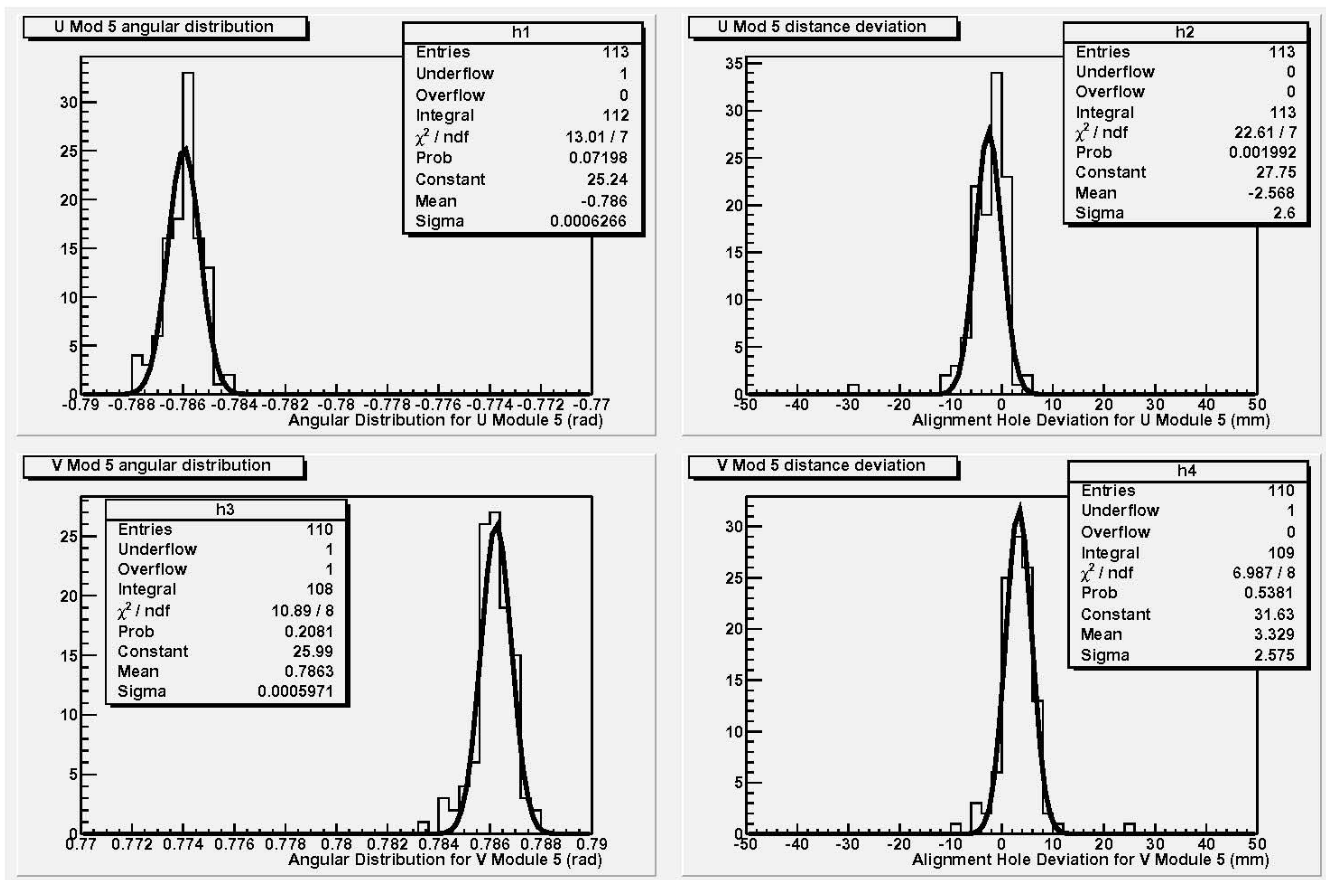

Figure 10 Module 5 alignments using virtual alignment hole correction.

Summary of Plot Data

The following tables summarize the angular and deviation fits from the plots in Figure 1 through Figure 10.

U module	mean angle	angle offset	angle sigma	mean deviation	deviation sigma
ideal U	-.7854	0	0	0	0
1	-.7854	0	.0009	0.13	2.53
2	-.7850	.0004	.0009	1.45	3.56
3	-.7857	-.0003	.0007	-1.34	2.89
4	-.7749	.0105	.0007	42.21	2.90
4 corrected	-.7859	-.0005	.0006	-2.31	3.21
5	-.7749	.0105	.0007	42.39	2.96
5 corrected	-.7860	-.0006	.0006	-2.57	2.60
6	-.7858	-.0004	.0008	-1.89	3.08
7	-.7859	-.0005	.0009	-2.18	3.12
8	-.7860	-.0006	.0009	-1.64	2.54

Table 2 Summary of U-plane module parameters from Gaussian fits. Angles are given in radians and deviations are in millimeters. The angle offset is the angle formed by the line joining the module alignment holes and the V axis.

V module	mean angle	angle offset	angle sigma	mean deviation	deviation sigma
ideal V	.7854	0	0	0	0
1	.7863	.0009	.0008	2.36	2.19
2	.7860	.0006	.0007	2.37	2.75
3	.7865	.0011	.0008	4.08	3.06
4	.7752	-.0102	.0006	-41.26	2.65
4 corrected	.7862	.0008	.0006	3.03	2.61
5	.7753	-.0101	.0006	-40.96	2.62
5 corrected	.7863	.0009	.0006	3.33	2.58
6	.7862	.0008	.0006	3.14	2.38
7	.7864	.0010	.0007	4.48	2.88
8	.7864	.0010	.0007	2.76	2.03

Table 3 Summary of V-plane module parameters from Gaussian fits. Angles are given in radians and deviations are in millimeters. The angle offset is the angle formed by the line joining the module alignment holes and the U axis.

Alignment with U and V Axes

As can be seen from Table 2 and Table 3, the width of the deviation distributions is typically between 2 and 3 mm, corresponding to an angular deviation of .5 to 1 mrad. This is in good agreement with the inherent positional uncertainty of the Vulcan measurements, which is found in ref [2] to be about 3.7 mm in the U-V plane for a distance based on two measurements (one at each alignment hole).

Module	Avg Offset	Offset Error	Avg Deviation	Deviation Error
U	-.0002	.0003	-0.9	1.2
V	.0009	.0003	3.2	1.1

Table 4 Average values of the angular offset and linear deviation for surveyed modules, exclusive of the bypass modules (4 and 5). Note (column 4) that a given offset will result in different deviations in modules of different lengths.

Two questions that may be addressed are a) whether the U and V modules are, on average, perpendicular to each other and b) whether the modules are, on average, actually aligned with the U and V axes. Table 4 lists the averages for surveyed U and V modules, taken from Table 2 and Table 3. The average excludes the bypass modules, since the offsets calculated for them were based on those of the other modules. The error on the average values is the sum in quadrature of the sigmas of the Gaussian fits divided by 6 (the number of module types used in the average).

Column 2 indicates that the modules are misaligned with the U and V axes by about 0.2 mrad and 0.9 mrad, respectively. The errors in column 3 are consistent with a U module alignment along the V axis and a V module misalignment of approximately 1 mrad. Taken at face value, the numbers in column 2 indicate that the modules, on average, are not quite perpendicular, the upper and lower quadrants being narrower than the east and west quadrants by about 1.1 mrad.

Conclusion

Analysis of the surveyed positions of the scintillator modules in supermodule 1 shows them to be well-aligned relative to each other. The modules for either U or V are parallel to within the resolution of the Vulcan Spatial Measurement System. The Vulcan data show the modules aligned to within 1 mrad. The distance deviations of the alignment holes that would be cause a 1 mrad shift in the angle are roughly equal to the Vulcan's resolution. While the supermodule 1 modules appear to be well-aligned relative to one another, they seem, on average, not to be precisely aligned along the U and V axes and not quite perpendicular.

I wish to thank Bernard Becker and Jeff Nelson for their helpful comments in the preparation of this note.

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[1] D. Boehnlein, *Quality Control Survey Measurements at the MINOS Far Detector*, NUMI-NOTE-GEN-868, September 2002.

[2] L. Mualem, *First Use of Module Survey Data from the Far Detector*, NUMI-NOTE-GEN-828, April 2002.